Ocean-Atmosphere State Estimation and Targeted Observing using Coupled Model Ensembles

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LONG-TERM GOALS

To build a regional ensemble-based Coupled Ocean Atmosphere Data Assimilation (DA) system that produces probabilistic analyses and forecasts of the ocean-atmosphere state that are significantly superior to those that are currently available. A cornerstone of this endeavour is the assimilation of observations of variables that are affected by both the oceanic and atmospheric state into coupled atmosphere-ocean models such as COAMPS®. Examples include scatterometer winds and low-peaking satellite radiance channels that are sensitive to both Sea Surface Temperature (SST) and low-level atmospheric temperature, moisture and aerosol.

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OBJECTIVE

Develop a cycling strongly coupled ensemble based data assimilation system for COAMPS® that enables ocean state estimates to benefit from observations of atmospheric variables that are influenced by the state of the ocean.

APPROACH

We have built a Hybrid coupled ensemble 3DVAR data assimilation scheme from the mesoscale ocean-atmosphere ensemble forecasting scheme for COAMPS® and the 3D-VAR version of the Navy Coupled Ocean Data Assimilation scheme (NCODA), which is currently being used for operations at FNMOC and NAVOCEANO. We have paid particular attention to observations of variables likely to be influenced by the oceanic state such as scatterometer near-ocean-surface winds and other low-level atmospheric observations. Data assimilation is a critical test of an ensemble forecasting system so we also took the time to use information obtained from the data assimilation cycle to improve the quality of the coupled ensemble forecasting system. Because of the high quality of coupled observations associated with it and the on-going Hydrology of the Mediterranean Experiment (HyMeX), we chose to focus on an area encompassing the Mediterranean as our first test region.

WORK COMPLETED IN FY13

(i) Improved the COAMPS® ocean ensemble for the Medeteranian domain by ensuring that the analysis error variance estimates used in the ET were consistent with innovation statistics from profile observations. (Frolov, Bishop, Holt)

(ii) Built and tested a cycling Hybrid data assimilation scheme that linearly combines a pre-existing static error covariance matrix with a localized ensemble covariance matrix using real observations. (Frolov, Bishop, Holt, Cummings)

(iii) Built and tested a cycling coupled data assimilation scheme that uses real atmospheric observations to adjust the oceanic state Currently, the forecast error covariance model for this coupled system is based solely on ensemble covariances because the pre-existing covariance model does not support covariances between atmosphere and ocean (Frolov, Bishop, Holt, Cummings)

(iv) Devised a perfect model data assimilation test bed in which pseudo-observations are generated from one of the ensemble members and the remaining ensemble members are used to produce a first guess, covariance matrix and an analysis. (Frolov, Bishop. Holt)

(v) Put together a first draft of a paper demonstrating the remarkable ability of scaterrometer winds observations to improve temperature and salinity fields in our perfect model data assimilation experiment. (Frolov, Bishop)

RESULTS

(a) Improvements to the ocean ensemble.

Validation of the legacy ET code for generating ocean ensemble showed that ensembles were grossly under-dispersive (Figure 1a). To constrain the variance of the ET ensemble to be consistent with observations, we used one-month of innovation histories to prescribe profiles of variance. Validation results with the improved ensemble (Figure 1b) show good agreement between ET ensemble variances and temperature innovations.

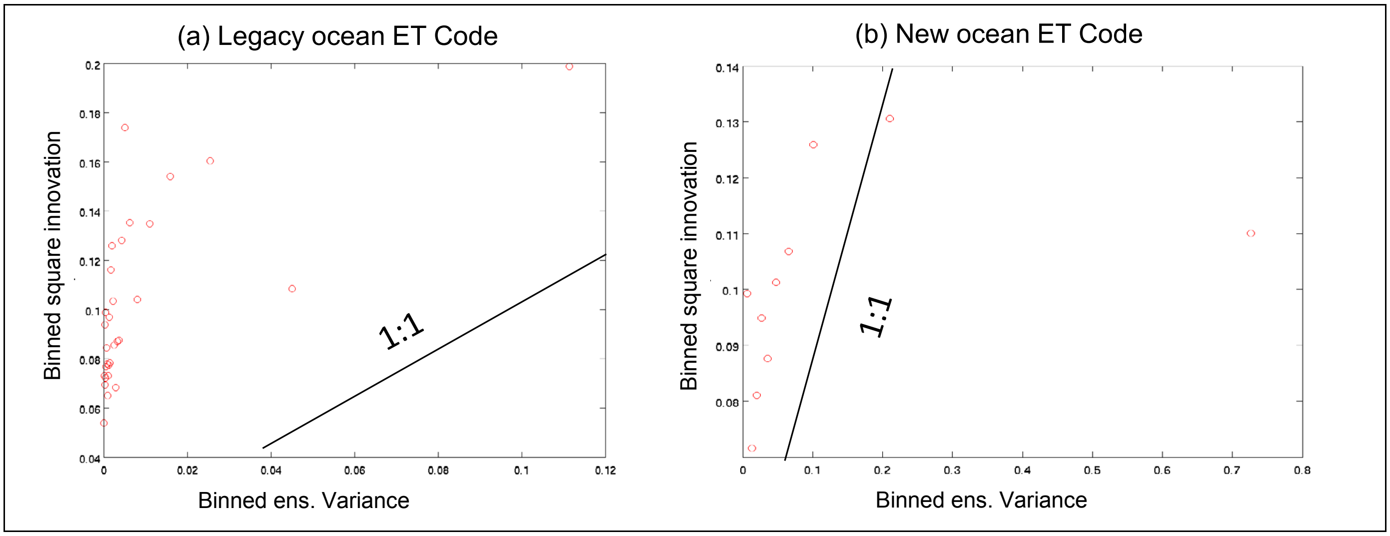

Figure 1: Ensemble spread diagnostics for ocean temperature

(b) Impact of scatterometer wind observations on ocean temperature and salinity analyses

To demonstrate the potential impact of atmospheric observations on ocean analyses, we devised an identical twin experiment. In the twin experiment, one of 80 coupled COAMPS® ensemble members was used to generate pseudo-scatterometer wind observations at every second ocean surface grid point while the other 79 members were used to produce a first guess, covariance matrix and an analysis. We used a simple Gapsari-Cohn horizontal localization with a radius of 200km. No localization was used in the vertical or in-between fluids.

Table 1: RMSE errors for the twin experiment with scatterometer winds.

	xt-xf	*xt-xa*	*Change*
Temperature (°C)	*0.52*	*0.49*	*6.3%*
Salinity (psu)	*0.11*	*0.10*	*5.6%*
U velocity (m/s)	*0.072*	*0.070*	*2.7%*
V vlelocity (m/s)	*0.071*	*0.069*	*3.0%*

Results of the twin experiment (Table 1) showed that assimilation of scatterometer wind data had a significant projection onto ocean fields and reduced errors in velocity by ~3%, temperature by ~6%, and salinity fields by ~6%.

Closer examination (Figure 2) of the analysis increments showed that spatial patterns of temperature and salinity increments (panels *a* and *c*) had strong similarity to the patterns of forecast errors (panels *b* and *d*).

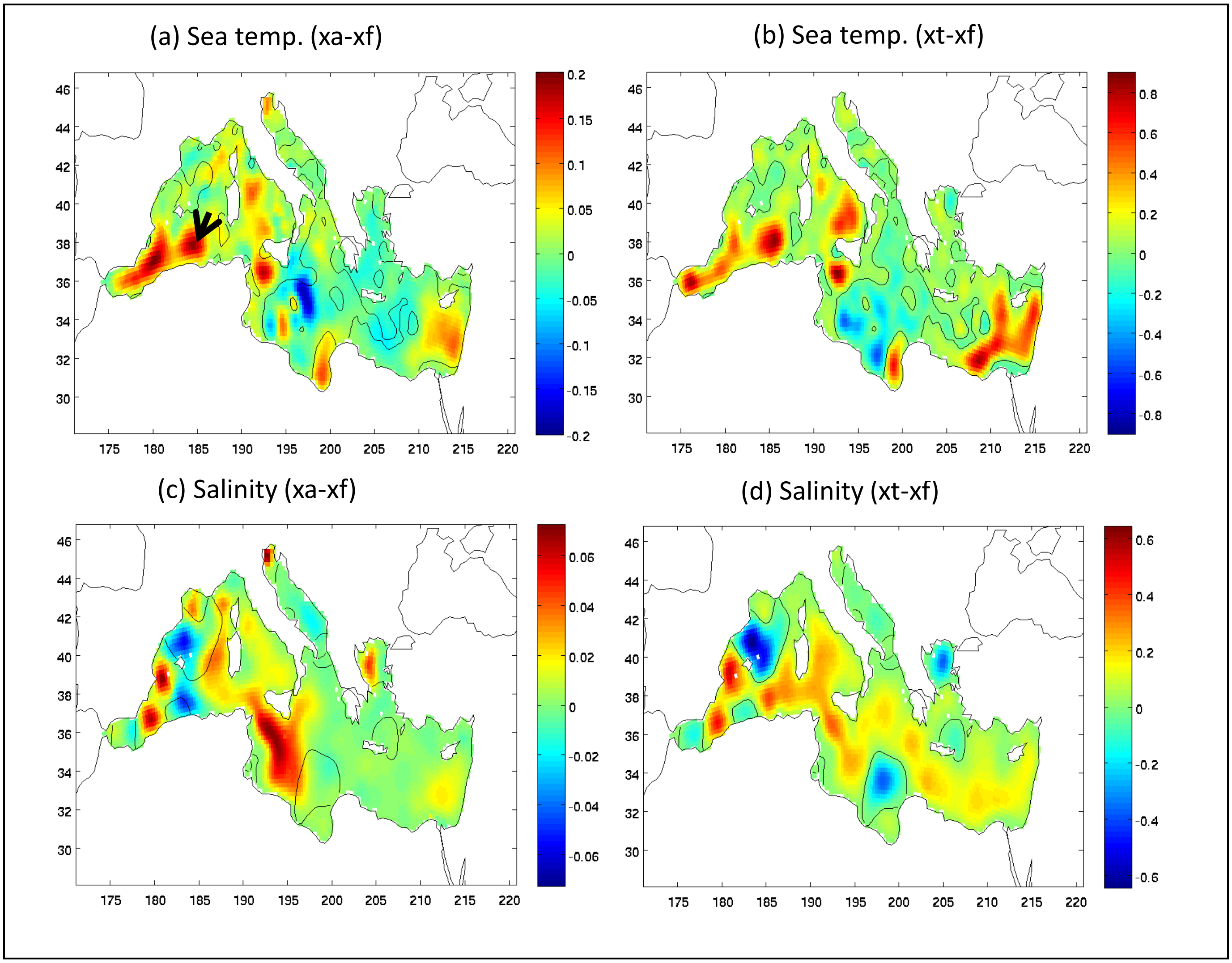

Figure 2: Surface maps of analysis increments (a, c) and forecast errors (b, d) for the 80-member twin experiment. Arrow in panel a shows the location of profiles plotted in Figure 3. The extent to which the left panels match the right panels shows the extent to which the assimilation step removed error from the state estimate.

We found that the analysis correction from the scatterometer wind observations extended through a considerable depth of the water column (red line in Figure 3). The importance of the spatial coverage of the scatterometer observations was highlighted by computing the correction field that would be obtained if there were only one scatterometer observation located at the horizontal grid point corresponding to the vertical profile of Fig. 3. This single observation correction is shown by the blue line in Fig. 3. Comparison of the blue line with the red line shows that the analysis correction from a single scatterometer wind observation is one or two orders of magnitude smaller than that due to all of the Mediterranean scatterometer observations. This finding demonstrates that much of the potential power of scatterometer wind observations to improve ocean state estimates is associated with the ability of this satellite based instrument to observe a large region of ocean surface winds.

(c) Effect of atmospheric observations on analysis and forecast skill in cycling system using real observations.

To further test the impact of atmospheric observations on the ocean analysis, we conducted a preliminary cycling experiment with real-world oceanic (SST and Argo profiles) and atmospheric data (boundary-level temperature and scatterometer winds). In this preliminary experiment we used 20 ensemble members that were localized using Gaspari-Cohn horizontal localization.

Table 2: Forecast errors (y-xf) for a cycling experiment with real data.

	Ocean NCODA	*Ocean Ensemble*	*Coupled Ensemble*
SST	*0.33*	*0.41*	*0.46*
Argo Temp	*0.30*	*0.28*	*0.26*
Argo Salt	*0.20*	*0.22*	*0.21*

The results of the cycling DA experiments (Table 2) show that (a) coupled DA had better representation of vertical temperature and salinity structure compared to the ocean-only ensemble; (b) ensemble methods had better representation of the vertical structure of the ocean temperature compared to the existing static NCODA covariance; and (c) ensemble methods had difficulty in fitting sea surface temperature signal.

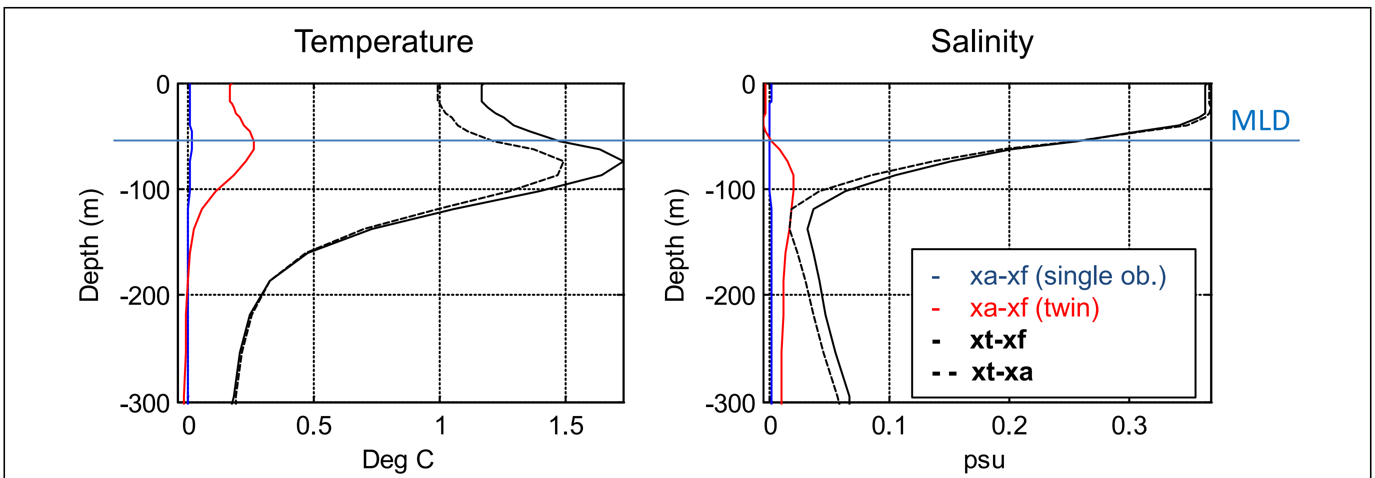

Figure 3: Profiles of error and increments for location 5W 38N. The black curve gives the correction that would remove all error. The red and blue curves give actual corrections.

These early results are encouraging and we expect further reductions in RMSE scores after we introduce improvements that will include using a larger ensemble size, vertical and inter-fluid localization, and improvements to the generation of the coupled ensemble.

IMPACT/APPLICATIONS

Superior ocean-atmosphere state estimation is the most likely impact of a successful fully coupled ensemble based data assimilation scheme – particularly in data sparse regions. The results of the preliminary experiments described above are very promising in this regard. Better state estimation will lead to better model error diagnoses and better forecasts of the ocean-atmosphere state. Our use of ensemble covariances in coupled data assimilation has and will continue to illuminate inadequacies of the current ensemble analysis system which, in turn, will lead to further improvements of the ensemble system and associated probabilistic forecasts. Better probabilistic forecasts will enable better uncertainty estimation which is critical for the Navy warfighter in interpreting signals from sonic and electromagnetic detection devices. In addition, superior ensemble covariances and localization methods should enable better adaptive sampling methods for environmental state estimation and Warfighter threat detection.

RELATED PROJECTS

"Telescopic 4D State Estimation". 10/1/12. Office of Naval Research. 3 years.
This project will use ensemble based data assimilation techniques to couple COAMPS atmospheric data assimilation with an ensemble data assimilation scheme for the Navy's global model.

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